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SUMMARY OF INVESTIGATIONS IN LATE PALEOZOIC GEOLOGY OF OHIO[1] [2]

MYRON T. STURGEON, Department of Geology, Ohio University, Athens, OH 45701

Abstract. This report summarizes the development of our understanding of the stratigraphy, paleontology and economic geology of the Carboniferous and Permian Systems of Ohio, and can conveniently be divided into four time units: prior to 1869, 1869–1900, 1900–1949 and 1949 to the present.

The first period was a time during which animals and Indians sought essential mineral substances and early explorers reported on geologic features and resources. Notes and reports were published on newly established mineral industries during and after settlement. This period also included publication of two annual reports describing the accomplishments of the short-lived First Ohio Geological Survey in the mid-1830's and publication of notes by individuals on general geology, fossils and mineral resources of the State between 1840 and the Civil War. Systematic investigation and reporting on Ohio's geology really began with the establishment of the Second Ohio Geological Survey in 1869 and has continued under three subsequent surveys. The distinguished staff of the Second Survey prepared and published reports on stratigraphy, fossils and mineral resources and the first geologic map including accompanying structure and stratigraphic sections. The Third Survey increased the emphasis on economic geology in its publications, and the Fourth and present Surveys have continued this attention in their appropriate reports and maps. In 1949 the Survey became a division in the Ohio Department of Natural Resources.

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This summary pertains to the development of our understanding of the geology of the Carboniferous and Permian Systems in Ohio, with emphasis on stratigraphy, paleontology and economic geology. Most consideration will be given to the Pennsylvanian System, since it has received more attention because of its large resources of important coals and ceramic clays. This report can conveniently be divided into several time units roughly corresponding with the several organizations of the Ohio Geological Survey: prior to 1869, 1969–1900, 1900–1949, and 1949 to the present. *Bibliography of Ohio Geology, 1819–1970,* published in four parts by the Ohio Division of Geological Survey, has been most useful in preparing this review. Only the more pertinent references are listed herein, and most sources of other cited references are available in the bibliography, where a total of more than 600 references are available.

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[2]Part of a Symposium on the History of Geology in Ohio, presented 2 April 1977 at the Ohio Historical Center.

PERIOD PRIOR TO 1869

Early Use of Minerals. The first individuals to seek and use the mineral resources of the Upper Paleozoic rocks in eastern Ohio were undoubtedly the animals requiring salt such as bison, deer, elk and bear as well as the extinct mammoth and mastodon (Hildreth 1838, p. 57; Stout, Lamborn and Schaaf 1932, p. 11), and animals such as birds, beaver and wasps using mud for plugging dams and building homes and nests. American Indians made the first human observations on the rocks in search of suitable materials for pigments, pottery, tools and weapons, but their early explorations, like those of the animals, are lost in the mists of unrecorded antiquity. The aborigines did find and use ironstones for decorative paints (Ohio Historical Society

1977), buff-burning clays for their pottery (Stout *et al* 1923, p. 7), excellent flint for their tools and weapons (Stout and Schoenlaub 1945, p. 7) and salt licks and salt springs for salt (Hildreth 1838, p. 57; Stout *et al* 1932, p. 11).

Early Sources of Salt and Development of the Salt Industry. Much of the information on salt in the early period has been taken from Bownocker (1906, pp. 9–18), Hildreth (1838, pp. 57–62) and Stout *et al* (1932, pp. 11–14). Hildreth's report was the original and principal source of information on early development of the salt industry for the other two reports.

Salt was not only a necessity for certain animals and for the Indians, but also for the first settlers in Ohio. The animals had long ago discovered and used salt seeps and springs, a number of which exist in the Pennsylvanian System of southeastern Ohio. The bison came in herds and developed well established trails that were still recognizable decades after those animals were extirpated from the State. Most likely the Mound Builders and certainly the later Indians appreciated the salt areas as sources of game animals and of the salt itself. The aborigines developed simple means of refining the salt by evaporation in sunlight.

One of the better known prehistoric salt sources was Scioto Saline along Salt Creek in Jackson County, where weak brine flowed from the Sharon conglomerate (Stout *et al* 1932, p. 11). Here the Indians, at low water stages during the summer, evaporated in sunlight the weak brine from the creek in basins dug in the sandstone. They continued this practice as late as 1815.

Manufacture of salt was the first mineral industry to be established in Ohio during its settlement as a territory. It is probable that French fur-traders knew of the salt sources in the State early in the 1700's and Virginia colonists definitely knew of them in 1755. Salt brought from the Atlantic seaboard cost $4.00 to $8.00 a bushel, and the early settlers eagerly sought local sources of that essential commodity. Possibly as early as 1795, and certainly by 1797 or 1798, the settlers started evaporation of brine in kettles at the Scioto Saline. The operation was expanded by 1800 and attained its maximum production between 1806 and 1808. Twenty furnaces were in operation and each furnace averaged 50 to 70 bushels of salt per week, which sold for $2.50 per bushel. Other sources of salt were soon discovered throughout the area of Pennsylvanian outcrops, and richer brines from these sources and from wells replaced the Scioto Saline as a source of salt. The National Congress as early as 1796, and later the Ohio Legislature, enacted several laws concerning salt sources and governing the salt industry in order to prevent the establishment of a salt monopoly. The danger of a monopoly was over by 1825 and the saline areas were sold.

Drilled wells soon replaced the seeps and springs as sources of salt because they yielded more copious and richer brines. The salt industry expanded into the Muskingum Valley in 1817, where production increased to between 300,000 and 400,000 bushels in 1833. Other early important producing areas were along Yellow Creek in Columbiana County, the Hocking Valley in Athens County and Leading Creek in Meigs County. In following decades, expansion continued in Athens, Columbiana, Guernsey, Meigs, Morgan and Tuscarawas Counties. Meigs County, in the vicinity of Pomeroy, became the largest and most important producer of salt from brines. The brine salt industry began a decline about 1870 as a result of competition from Silurian rock salt, first in Michigan and later in northeastern Ohio, with an accompanying decline in price. Production from brines has, however, continued until recently at Pomeroy, and brines are still a source of magnesium and of various materials for chemical industries (Stout *et al* 1932, p. 9).

Flint and Its Uses. Flint, which was so essential to the American Indians and their culture, was also a necessity to the pioneers for buhrstones used in grinding their grain in water-powered mills. In Ohio, flint occurs locally in certain Pennsylvanian marine strata, *viz.*, Boggs, Brush Creek, Cambridge, Mercer, Putname Hill, Vanport and Zaleski members. The Vanport flint on Flint Ridge in Licking County and near McArthur in Vinton County was the principal source of buhr-

stones. Quarrying of buhrstones continued until approximately 1840 (Stout and Schoenlaub 1945, pp. 7–8). Flint was also used in flintlock rifles of the pioneers, but Ohio's flints were not of high enough quality for this purpose. Today flint is used only for decorative purposes and is Ohio's "gemstone".

Coal and Development of Coal Mining and Use. Eavenson's The First Century and a Quarter of American Coal Industry, privately published in 1942, was the source of much information for the following summary. The Indians did not mine or use coal except for black pigments and ornaments carved from cannel coal since wood was plentiful for fuel. The early European explorers and traders certainly saw numerous exposures of coal but recorded few notes of their observations. Maps by Pattin in 1752 (Eavenson 1942, Map 3, between pp. 6 and 7) and Evans in 1755 (Eavenson 1942, p. 7) show or mention coal in the Ohio Country and on the Hockhocking and Muskingum Rivers. In 1755, Evans reported coal on fire near the present location of Bolivar in Tuscarawas County in 1748 (Eavenson 1942, p. 19). Notes of those times commonly referred to coal as "sea coal", "mineral coal" or "stone coal" to distinguish it from charcoal. Mention of coal became more frequent as surveying, sale and settlement of Ohio's lands progressed. The early settlers made some use of coal for heating and blacksmithing where it was easily available locally, but wood was so abundant that it was the usual fuel. Except for local use, coal mining did not develop in the State until after 1800. Coal could not be moved easily or economically to distant markets except along the larger streams such as the Muskingum and Ohio Rivers. Coal mining began near Pomeroy in 1806 with shipment on log rafts, but was unsuccessful. In 1808 a mine was opened in Springfield Township, Summit County and the coal was hauled to market in wagons. Mention was made of abundant coal and iron ore near Zanesville in 1810. Mining of coal in Perry County began in 1816, "Coal mines were reported as plentiful in Athens County" in 1817, successful mining and shipping of coal were resumed at Pomeroy in 1819 and coal was mined in Jackson County and used for salt manufacture in 1823 and later in the metallurgy of iron. Coal was used not only for heating and blacksmithing purposes but also for evaporation of brines, to heat steam boilders, and in iron blast furnaces and forges. Recorded prices indicate that coal sold for 3 cents a bushel at Marietta in 1812 and was almost as cheap at Zanesville. In 1810, coal shipped from Pomeroy to Louisville, Kentucky sold for 25 cents a bushel or $6.25 a ton.

The coal industry received a big stimulus with the digging of canals, and the first coal shipments via canals were made in the late 1820's. Numerous new mines were opened along the canals wherever good minable coal was available. In 1852, 392,520 tons of coal were hauled on Ohio's canals, but 1850 is an approximate date when the railroads began to encroach upon the freight formerly transported on canals. Increases in population and in the use of coal, as well as improved transportation facilities on canals and railroads, resulted in marked increases in production of coal as shown in table 1.

TABLE 1
*Coal Production in Ohio 1800–1870.**

Year	Production in tons
1800	100
1805	800
1810	2,700
1815	11,350
1820	32,750
1825	78,600
1830	106,900
1835	183,642
1840	401,550
1845	775,870
1850	1,950,250
1855	6,780,500
1860	9,913,000
1865	9,512,988
1870	11,942,355

*Taken form Collins (1976).

S. P. Hildreth, in 1828 and 1836 (1835), published noteworthy contributions to information on coals of the Ohio Valley region, with the latter being a lengthy report in the American Journal of Science.

In the same period before 1868, E. B. Andrews (1864), L. Lesquereux (1852), H. D. Rogers (1843), B. Silliman (1859), B. Tappan (1830) and C. Whittlesey (1853, 1854) published notes on Ohio's coals including cannel coal, which was distilled for the production of coal oil (kerosene) for lamps, before Drake's discovery of oil at Titusville, Pennsylvania in 1859.

Iron Ores, Iron Furnaces and the Iron Industry. Native ironstones including hematitie, limonite and several varieties of siderite, found mostly in the Pennsylvanian System and abundant hardwood forests as a source of charcoal, were the bases for establishing an iron industry as early as 1804, which has grown into our modern steel industry dependent upon outside fuels and ores. Limitations do not permit delving fully into the details of the origin and growth of the iron industry, but a brief statement concerning the early importance of our native ironstones is given by Stout (1945, p. 3):

> "In Ohio some utilization for the smelting of iron has been made of iron ores and of ferruginous rocks found in a wide expanse of strata, ranging through certain beds from the Brassfield limestone in the Silurian system to the Creston Red beds in the Permian system and on even to the bog ores laid down since the retreat of the Wisconsin glacier. The ores that were of prime importance, however, fall in the Pottsville and Allegheny series of the Pennsylvanian system and were smelted in the furnaces in the belt extending from Scioto and Lawrence counties on the Ohio River to Mahoning and Columbiana counties on the Ohio-Pennsylvania state line. Various deposits were used in other areas. The native ores thus supported the charcoal iron industry of the State—eighty-six furnaces in all—that began with the erection, in 1804, of Hopewell furnace on Yellow Creek in Mahoning County and closed with shutting-down, at 3 P.M. December 26, 1916, of Jefferson furnace near Oak Hill in Jackson County. Also throughout most of the active life of the fifty-six coal furnaces erected between 1845, Mary at Lowellville, and 1887, New York at Shawnee, the ferruginous part of the burdens consisted entirely or largely of ores gathered not far distant from the stacks. Further, many of the more modern coke furnaces built between 1863 and 1895 used some native ores along with that from outside sources. The smelting of Ohio ores thus ceased about 1923. Of the total of 226 blast furnaces built in Ohio all but about 60 have smelted native ores, over one-half nothing else. The period of such utilization was thus about 119 years, from 1804 to 1923. The Ohio ores still have a future."

Each early iron furnace was the center of a self-sufficient community which was dependent upon the furnace and employed ore miners, charcoal producers and other essential miscellaneous workers. Stout also compiled a comprehensive history profusely illustrated with photographs of our early iron industry. It is unfortunate that this history has never been published, although to publish it with all its photographs would cost a mere fraction of the cost of a mile of new highway and it certainly would last much longer than the pavement.

Clays, Shales and the Ceramic Industry. Ohio has been the leading state in the manufacturing of ceramic products for many years and the principal basis of this top position has been the excellent Pennsylvanian underclays of the Allegheny and Pottsville Groups, although other high quality raw ceramic materials occur in the Mississippian System. Need for ceramic wares and readily available surface and coal formation clays led to the early establishment of small ceramic factories, many of which were operated part-time by farmers originally for the manufacture of building bricks and soon afterwards of earthenware and stoneware pottery. The buff-burning coal formation clays were very satisfactory for the manufacture of stoneware, yellow ware and Rockingham. The first potteries using coal formation clays were started at Steubenville in 1806 and at Zanesville in 1808. Many additional plants were established until, in 1840, the 6th census recorded the number of potteries in the Pennsylvanian-Permian area (table 2). In that year, those factories in operation produced wares exceeding $65,000 in value. The ceramic products not only supplied the local markets, but were sold as far south as New Orleans. In the area under consideration, the ceramic industries continued to develop, with some lag during the Civil War in the latter part of the century. Important pottery centers developed, notably in Crooksville, Roseville, East Liverpool, Zanesville, and numerous lesser centers elsewhere. A wide variety of ceramic

TABLE 2
*Number of Potteries in the Pennsylvanina-Permian Area in 1840.**

Ohio County	No. of Potteries
Belmont	1
Columbiana	5
Guernsey	2
Harrison	3
Holmes	2
Knox	1
Lawrence	2
Licking	?
Monroe	2
Morgan	1
Muskingum	22
Perry	2
Portage	1
Stark	11
Summit	5
Tuscarawas	2
Wayne	1
Total	63

*Taken from Stout *et al* (1923).

products have been manufactured including chemical stoneware, conduits, cooking and serving wares, fire proofing, hollow blocks, jugs, knobs, paving bricks, refractory bricks, retorts, roofing tiles, several varieties of building bricks, silica bricks, sewer pipes, terra cotta, various tiles and many other minor products. Stout *et al* (1923, pp. 7–102) has published a detailed history of the clay industry in Ohio.

Building Stones. Another geologic resource used extensively by early Ohioans was building stones. Upper Paleozoic rocks have an abundance of sandstones suitable for building and other purposes. Useful and widely used Mississippian sandstones include the high quality Berea and Buena Vista Sandstones and the Euclid Bluestone of the Bedford Shale, several sandstones including the Black Hand Sandstone of the Cuyahoga Formation and Byer and Vinton Sandstones of the Logan Formation. The Pennsylvanian System has numerous suitable sandstones including the better known Bakerstown, Bellaire, Buffalo, Clarion, Connelsville, Cow Run, Freeport, Gilboy, Grafton, Mahoning, Massillon, Sharon and Sewickley members that were widely used mostly for local purposes. Thick, suitable sandstones, including the Fish Creek, Gilmore, Hundred, Jollytown, Mannington, Marietta, Niveveh and Waynesburg, occur in the Dunkard Group and have been used to some extent, especially for grindstones.

Principal uses of sandstone employed by the pioneers and later Ohioans included bridge abutments and bridges for roads and railroads, buildings, canal locks, caps and sills, chimneys and chimney caps, coping, curbstone, flagstone, foundations, grindstones, pavements and miscellaneous uses. Quarrying operations developed and increased throughout the 1800's but sharply declined with the increased use of concrete near the turn of the century. Bownocker (1915) published a bulletin on the building stones of Ohio.

First Ohio Geological Survey. Only brief mention of the First Ohio Geological Survey need be made here, as its history was summarized by Hansen and Collins (1979). The survey was authorized in 1836 and continued for only two years. C. Briggs, J. W. Foster, S. P. Hildreth, J. Locke and C. Whittlesey made brief reconnaissance observations and reports on Upper Paleozoic rocks in W. W. Mather's two annual reports (1838a, b), G. P. Merrill (1906, p. 333) gave the following summary of the first survey's accomplishments:

> "The general results of the survey may be summed up as follows: The principal formations, as indicated, beginning with the oldest, are first, the great limestone deposit (Silurian and Devonian) which was erroneously regarded as equivalent to the Mountain or Carboniferous limestone of Europe. This was found in Adams County, extending thence to the western portion of the State. It was felt by Locke as not unreasonable to suppose that the particles composing it were once held in aqueous solution and subsequently deposited in tranquil waters along the bottom of the ocean. This may then have been consolidated by subterranean heat. Overlying this is a bed of shales (Upper Devonian) two or three hundred feet in thickness, black, fissile, and with a fetid odor. Next comes Waverly sandstone, the series being thus first named. Fourth, a conglomerate cropping out on the western border of the Coal Measures and varying in thickness from 80 to 100 feet. Fifth, a lower coal series, consisting of alternations of sandstone, shales, limestone, iron ores, and

coals, some 300 feet in thickness. Sixth, buhrstone. Seventh, the upper coal series, made up of sandstones, shales, coal, iron ores, and limestones. Eighth, the Tertiary deposits, under which head he included the prairies or barrens in the western part of the State, and the pebble beds and boulders of primitive rocks so abundant in some parts of the Scioto Valley; and ninth, the recent deposits, including as such those now forming along the river beds. The beds were noted as having generally but a slight dip and irregular undulations. Locke found near the boundary of Ohio and Indiana a summit level and an anticlinal axis from which the strata dipped in opposite directions, eastwardly in Ohio and westwardly in Indiana. This is apparently the first recognition of what has since become known as the Cincinnati Uplift."

Other Reports on General Geology. In addition to the reports issued by the First Survey, Atwater (1819) and Whittlesey (1869) made brief general reports on the geology of eastern Ohio in the American Journal of Science and in a memoir of the Boston Society of Natural History, respectively.

Paleontological Reports. The abundant and conspicuous fossil plants in the Pennsylvanian System soon attracted attention and a dozen notes and brief reports concerning them were published prior to 1870 by Brongniart (1828, 1828–1838), J. W. Foster (1853), E. Granger (1821), S. P. Hildreth (1827), J. P. Kimball (1857), S. G. Morton (1836 [1835]), J. S. Newberry (1853a, b; 1853/1854; 1856a, b, c) and C. Whittlesey (1849). Kimball's, Morton's and Newberry's reports are the most extensive and are presumably among the more important.

J. W. Foster (1852), Foster and Dill (1851), J. Hall (1863), S. G. Morton (1836), J. S. Newberry (1856c; 1857 and 1868), R. P. Stevens (1858a, b), E. de Verneuil (1846) and J. Wyman (1857) published a dozen notes and short reports on fossil invertebrates and vertebrates. Hall's notice of Waverly crinoids, Morton's inadequate descriptions of Carboniferous invertebrates, Newberry's notes and descriptions of fossil Carboniferous vertebrates, Steven's descriptions of Carboniferous invertebrates, de Verneuil's note on *Fusulina* and Wyman's note on vertebrates are the more significant among these notes and descriptions.

PERIOD OF 1869–1900

The financial panic of 1837 and petty internal jealousies caused the termination of the First Ohio Geological Survey in 1838. Private investigators continued geologic observations mostly on economic geology but only a few notes and short reports were published, as previously noted. Systematic examination and publishing on Ohio's geology really began with the establishment of the Second Ohio Geological Survey in 1869 and continued under the Third Ohio Geological Survey in the middle 1880's. The Second Survey's staff included such outstanding persons as J. S. Newberry, Chief Geologist; E. B. Andrews and Edward Orton, Sr., Assistant Geologists; F. B. Meek, Paleontologist and T. G. Wormley, Chemist. The Third Survey had such well known men as Edward Orton, Sr., State Geologist, and N. W. Lord, Chemist. In addition, there were several notable special assistants and volunteers including E. D. Cope, J. Hall, M. C. Read, J. J. Stevenson and R. P. Whitfield who observed and reported upon the Upper Paleozoic rocks and their economic resources and fossils.

Accomplishments of the Second Ohio Geological Survey. The Second Survey, between 1869 and 1882, published two Reports of Progress for the years 1869 and 1870 and four volumes. Volumes 1 and 2 are in two parts, part 1 of each devoted to geology and part 2 to paleontology, Volume 3 is entirely physical geology and Volume 4 is a report on zoology.

Newberry (1871 [1870]a) summarized the progress of the geologic work in 1869 and included brief mention of some details of Carboniferous (Mississippian and Upper Devonian) and of Coal Measures (Pennsylvanian) stratigraphy with notes on the economic geology of coal, iron and steel, salt and clays. Andrews (1871b, c, d) who taught geology at Marietta College and who was also the leading authority on geology of southeastern Ohio, reported on stratigraphic and economic geology with some references to fossils in the Second Geological District which included southeastern Ohio south of the Central Ohio Railroad and extended to Adams and Franklin Counties far enough to include the area of exposed Ohio Shale.

Newberry (1871 (1870]a) also prepared the first, and remarkably accurate, geologic map of the State from notes of the Survey's field geologists. The Report of Progress in 1870 was published in 1871. In this report, Newberry (1871a, b) gave a 40-page introduction to the Lower Coal Measures in northeastern Ohio with special attention to the coals and iron ores and with mention of various fossils collected. Andrews' report (1871d) on the 2nd District totaled almost 200 pages devoted to stratigraphy and economic geology, and included chemical analyses by Wormley (1871) and heating tests on coals by T. C. Mendenhall (1871).

Volume 1, Part 1, Geology, published in 1873, contains short county reports within the area of Upper Paleozoic strata of Ashtabula, Geauga, Lake and Trumbull Counties by Read (1873), on Cuyahoga and Summit Counties by Newberry (1873b), all in northeastern Ohio, and on Athens, Gallia, Meigs, Morgan and Muskingum Counties by Andrews (1873) in southeastern Ohio. Volume 1, Part 2, Paleontology, was also published in 1873 and included two reports by Newberry (1873c, d), the first on fossil fishes, primarily those of the Devonian System but with some mention of those in the Subcarboniferous (Mississippian) and Coal Measures (Pennsylvanian) Systems. The second report was one of 25 pages describing fossil plants from the Coal Measures. Both of these reports were illustrated by carefully drawn figures on 25 plates. Volume 2 followed the same plan of organization as Volume 1 with one part on geology and a second part on paleontology published in 1874 and 1875, respectively. Newberry (1874a) published a 100-page introduction to the Carboniferous System and included all three of the systems under consideration. Newberry (1875) resumed descriptions of Carboniferous (in part, Devonian) fossil fishes in Part 2. Two outstanding paleontologists, James Hall and R. P. Whitfield (1875) described Waverly (Mississippian) crinoids. Two other distinguished paleontologists described Mississippian and Pennyslvanian fossils, F. B. Meek (1875) reported on available Waverly and Coal Measure invertebrates. E. D. Cope (1875a, b) summarized on extinct amphibians from the renowned locality at Linton in northeastern Jefferson County. Andrews (1875) described a very unusual fossil flora found near the base of the Coal Measures approximately two miles east of Rushville in Perry County. This distinctive and unusual flora has subsequently been found at several widely separated places in eastern North America. Each fossil report was illustrated by well done and appropriate plates and figures. Volume 3, 1878, has only Part 1, Geology, and includes pertinent county reports on Columbiana, Jefferson, Mahoning, Portage, Stark and Tuscarawas Counties by Newberry (1878a, b) on Belmont, Carroll, Guernsey, Harrison and Muskingum Counties by J. J. Stevenson (1878); on Ashland, Holmes, Huron, Knox, Licking, Richland and Wayne Counties by M. C. Read (1878a, b); on Medina County by A. W. Wheat (1878); on Coshocton County by J. T. Hodge (1878); on Franklin County by E. Orton Sr. (1878a); a report on the Hocking Valley coal field by Read (1878c) and supplemental reports on Perry and portions of Hocking and Athens Counties by E. B. Andrews (1878) and a report on the Hanging Rock District by Orton Sr. (1878b).

Accomplishments of the Third Ohio Geological Survey. Orton directed attention of the Third Survey primarily to economic considerations of coals, clays and iron ores, although county surveys continued to be published and Whitfield published on Mississippian and Pennsylvanian fossils. Some attention was also given to archaeology and botany. The Third Survey's first publication was Volume 5, published in 1884. This volume contains long reports, totaling 585 pages, by Orton Sr. (1884a, b, c) on the stratigraphy and coal seams of the Lower Coal Measures including a detailed and comprehensive 80 page report on the Hocking Valley coal field, which at that time was probably the largest producing coal area in the State. A variety of other subjects were also treated in Volume 5, including coal mining by Andrew Roy (1884e), iron ores by Orton Sr. (1884c), iron manufacture by N. W. Lord (1884b), the manufacture of coke by Henry Newton (1884), building stones by Orton Sr.

(1884d), clays and clay industries by Edward Orton Jr. (1884), gas coals by E. McMillin (1884), the Meigs Creek coal in Guernsey, Morgan, Muskingum and Noble Counties by C. N. Brown (1884) and chemical reports by Lord (1884c). The stature of Edward Orton Sr. as a geologist is well shown by these extensive reports including Volume 7 and by the fact that he was not only a productive State Geologist but also part of the time President of Ohio State University and full-time Professor of Geology and Chairman of the Department of Geology in the University. The quantity and quality of his contributions are the mark of a truly great geologist.

Volume 6, published in 1888, was devoted largely to oil and gas, in which Orton established himself as one of the pioneers in the understanding of basic geologic aspects of the petroleum industry and in urging conservation practices in that industry. Most consideration of oil and gas was on that of the Ordovician Trenton Limestone but Orton (1888) included a 98-page report on the Berea Grit as a source of oil and gas and F. W. Minshall (1888) summarized a history of the development of the Macksburg oil field. C. N. Brown (1888) gave a brief account of the Pittsburgh coal in east-central Ohio; E. Lovejoy (1888) on the Pomeroy and Federal Creek coal fields and W. J. Root (1888) on manufacture of salt and bromine.

Volume 7, published in 1893, continued the economic treatment of clays and coals by the Ortons (Orton Sr. 1893b, c; Orton Jr. 1893), but more than two-thirds of its pages were devoted to archaeology and botany, notes on the Waverly Group by C. L. Herrick (1893); Fossils of Silurian and Ordovician rocks reported by the paleontologists, A. F. Foerste and E. O. Ulrich, Devonian fishes by E. W. Claypole and A. A. Wright (1893), descriptions of Devonian, Mississippian and Pennyslvanian invertebrates by R. P. Whitfield (1891/1893). A new edition of the State Geologic Map, bearing the date 1894, by Orton Sr. (1893a) was also included in Volume 7. Appropriate maps were included in each of the three volumes of the Third Survey.

More than 50 notes and reports were published by various authors including E. B. Andrews (1871a; 1875/1876a, b; 1879), E. W. Claypole (1884a, b; 1887; 1895), J. C. H. Cobb (1887), W. F. Cooper (1888, 1890), E. D. Cope (1872, 1873, 1874, 1875a, b), H. P. Cushing (1888), A. Foerste (1887, 1893), R. Hazeltine (1883, 1885), C. L. Herrick (1887, 1888, 1889), H. Herzer (1893a, b; 1897), L. E. Hicks (1878, 1879), T. S. Hunt (1874), F. H. Knowlton (1893), N. W. Lord (1884a), F. B. Meek (1871a, b), S. A. Miller and C. L. Faber (1892), J. S. Newberry (1874c, d, e, f, g; 1883, 1884), M. C. Read (1883), A. Roy (1876; 1882; 1883a, b; 1884a, b, c, d; 1885; 1887; 1888; 1890; 1894; 1899), S. H. Scudder (1888), J. J. Stevenson (1892), E. O. Ulrich (1888), A. W. Vodges (1888), C. A. White (1871), I. C. White (1879, 1891), R. P. Whitfield (1881, 1882), C. Whittlesey (1872a, b; 1873; 1874; 1875; 1877a, b; 1878, 1879, 1880, 1883, 1884), H. S. Williams (1891), and A Winchell (1871) on stratigraphy, economic geology and paleontology during the 1869–1900 period. Publication outlets included the American Journal of Science, American Geologist, American Naturalist, Academy of Natural Sciences of Philadelphia, Boston Society of Natural History, Denison University Scientific Laboratories Bulletin, New York Academy of Sciences, Ohio State Academy of Science, Ohio Mining Journal, Science and others.

During the last 30 years of the 1800's, such mineral industries as the clay and coal industries continued to grow and others such as iron ore, building stones, and salt dependent upon brines declined. The declining industries did not expire instantly, and we have already noted a few details of the declining salt industry. Between 1880 and the mid-1880's, 30,000 tons of local iron ore were shipped annually from the Village of Creola in Swan Township, Vinton County. As late as 1890, 200 pick, shovel and wheelbarrow miners were hand picking placers for kidney iron ore along Middle Fork of Little Beaver Creek in Center Township, Columbiana County, and the royalty was reported to be $10,000 per acre on those placers (D. Reese 1942).

PERIOD OF 1900–1949

Edward Orton, Jr. was the first State Geologist of the Fourth Ohio Geological Survey established in 1900, and he served for six years. J. A. Bownocker succeeded Orton, Jr. and served until his death in 1928. He was followed by W. E. Stout who served until his retirement in 1946. G. W. White and J. H. Melvin served, in turn, until the end of the period. A cooperative arrangement with the U.S. Geological Survey provided for mapping the entire State with 15-minute topographic maps, which greatly facilitated geologic field work. The Survey's program included normal stratigraphic and economic investigations, areal reports, major revision of the Pennsylvanian System, a revised enlarged edition of the geologic map and two paleontologic reports.

The Fourth Ohio Geological Survey. During Orton, Jr.'s tenure, bulletins were issued on oil and gas (Bownocker 1903), cement (Eno 1904, Bleininger 1904), sand lime brick (Peppel 1905), revision of nomenclature of Ohio geological formations (Prosser 1905), limestone (Orton, Jr. and Peppel 1906), and salt and salt industry (Bownocker 1906). A number of significant bulletins were printed while Bownocker was in office. W. C. Morse (1910, 1911) was the author of a bulletin on the Maxville Limestone and a report on its fauna. Prosser (1912) published a detailed account of the Devonian and Mississippian formations in northeastern Ohio. D. D. Condit (1912), one of the ablest geologists ever to work in Ohio, published an excellent reconnaissance survey of the Conemaugh Group, and C. G. Mark (1912) reported on the fossil invertebrates collected during that survey. Bownocker's report (1915) on building stones was an adequate summary of that declining industry.

Wilber E. Stout (1916) published the first of several informative and practical areal reports, *Geology of Southern Ohio*, followed by Muskingum County (1918), Columbiana County (with R. E. Lamborn 1924), and Vinton County (1927). He also published alone or with others important reports on coal formation clays (1923, 1931b, 1940), cycles (1931a), brines (1932), iron ore formations (1945 [1944]), water (1943), flint (1945) and compiled exhaustive unpublished reports on the Monongahela Group and a comprehensive illustrated history of Ohio's early blast furnaces. Stout was a most remarkable man with keen powers of observation, a perfect photographic memory and genuinely respected by persons in the mineral industries. He spent 17 field seasons in eastern Ohio and measured thousands of rock exposures. His field notes are very brief but in his prime he could have quoted the details and the measurements of any one or all of those exposures with complete accuracy. His philosophy for geologic field work was simple: 1) dig out completely and measure the full thicknesses of coals, 2) if you meet people who want to talk give them opportunity to talk, 3) when you are tired quit for that day because what you do after that will be worthless. In his remarkable way Stout was a great geologist and he ranks among Ohio's top geologists with John S. Newberry and Edward Orton, Sr.

Other significant reports include Stauffer and Schroyer's Dunkard bulletin (1920), Conrey's Wayne County (1921), Hyde's Camp Sherman quadrangle (1921), Westgate's Delaware County (1926), Lamborn's Jefferson County (1930) and G. W. White's Holmes County (1949). Economic reports in addition to those of Stout's already mentioned are Foulk's industrial water supplies (1925), Bownocker and Dean's coal analyses (1930 [1929]), Lamborn, Austin and Schaaf's shales and surface clays (1938) and Lamborn's coals of Carroll and Mahoning Counties (1942). Morningstar's excellent report (1922) on the Pottsville fauna filled a large gap in knowledge of our Pennsylvanian marine invertebrates.

PERIOD 1949 TO PRESENT

Ohio Division of Geological Survey. In 1949 the Ohio Geological Survey became the Division of Geological Survey in the Ohio Department of Natural Resources. Its activities continued much the same as those of the Fourth Survey. Its field programs were facilitated by the topographical remapping of the State with 7½-minute maps. County reports con-

tinued to be published and more recently were supplemented by preparation and publication of geologic quadrangle maps and brief reports. County reports published include: Athens (Sturgeon *et al* 1958), Coshocton (Lamborn 1953), Morgan (Norling 1958), Perry (Flint 1951), Stark (DeLong 1963), Tuscarawas (Lamborn 1956), Washington (Collins and Smith 1978). The U.S. Geological Survey published a detailed report on Belmont County (Berryhill 1963) and on Portage County (Winslow and White 1966). Coal resources received attention of Brant (1954, 1956), Brant and DeLong (1960), Collins (1976), DeBrosse (1957), DeLong (1955, 1957), Denton (1959, 1960), Granchi (1958), G. E. Smith (1952), W. H. Smith (1951) and others in various publications. Lamborn (1951) published a bulletin on limestones of eastern Ohio. Marple edited Hyde's (1953) report on Mississippian formations of central and southern Ohio, which was in manuscript before his untimely death in the mid-1930's. A number of economic and stratigraphic reports have been issued as reports of investigations and information circulars. Outcrop maps (15-minute) have been compiled for important Pennsylvanian coals and limestones for limited areas and for the Mississippian-Pennsylvanian contact.

In other publications, uncerclays have been discussed by Parham (1964), Schultz (1958) and Smith and O'Brien (1962, 1965). Martin *et al* (1957, 1965) have published important papers on sandstones of the Dunkard Basin. Potter and Siever (1956) and others have made regional studies of sources and distribution of Pennsylvanian sediments. Earlier, Wanless (1939) attempted correlation of Pennsylvanian strata in the Eastern Interior and Appalachian Basins, and later he and his students made significant studies on deposition of Pennsylvanian sediments. Ferm (1970) and his students have made similar studies on a regional scale. Three very important contributions to our understanding of the formations in the Dunkard Basin are those of Cross, Smith and Arkle (1950), Cross, *et al* (1958) and Barlow and Burkhammer (1975), the latter being a symposium on the *Age of the Dunkard.* Since 1900 a large amount of information pertaining to our Upper Paleozoic systems has been published in scientific journals, proceedings and transactions of scientific societies and in unpublished theses. These are too numerous to be listed here, although many of them are significant contributions.

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